Effects of diet quality on energy expenditure by 20-month-old Alpine, Angora, Boer, and Spanish wethers

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Abstract

Six Alpine (47.7 ± 1.36 kg initial BW), Angora (28.8 ± 1.11 kg), Boer (87.5% Boer and 12.5% Spanish; 49.3 ± 2.17 kg), and Spanish (38.7 ± 0.51 kg) wethers (initial age of 19 months) were used to determine effects of genotype and diet quality on energy expenditure (EE) when fed near maintenance and fasted. The experiment consisted of four simultaneous crossovers, with 21 days for adaptation before measures. Diets were 65% concentrate (CON) or coarsely ground alfalfa hay (FOR). EE was determined from O_2 consumption and production of CO_2 and CH_4 with a head-box respiration calorimetry system, along with urinary N excretion, over 2-day periods in fed and fasted states (4 days fast). EE was expressed on the basis of average BW during the fasted measurement period. There were only significant interactions between genotype and diet in DM and gross energy intakes, which were due to differences in magnitude. Intake of ME was similar among genotypes and slightly greater ($P < 0.05$) for CON than for FOR (450 kJ/kg versus 424 kJ/kg $BW^{0.75}$). Neither diet (373 and 371 kJ/kg $BW^{0.75}$ for CON and FOR, respectively; S.E. = 5.9) nor genotype (377, 377, 361, and 373 kJ/kg $BW^{0.75}$ by Alpine, Angora, Boer, and Spanish, respectively; S.E. = 9.3) influenced fed EE ($P > 0.10$). Fasted EE was similar between diets but was greatest among genotypes ($P < 0.05$) for Alpine (251, 224, 217, and 225 kJ/kg $BW^{0.75}$ by Alpine, Angora, Boer, and Spanish, respectively; S.E. = 7.2). In summary, based on fasting measures, it would not appear that dairy goat breeds, such as Alpine can minimize EE to the extent of other genotypes in response to very severe nutrient restriction, such as fasting. With mature, nonlactating goats and a level of feed intake near the ME_m assumed for a constant and nonlimiting plane of nutrition, ME_m may not differ markedly among genotypes. Although, higher levels of intake to support growth, milk production, or fiber growth could conceivably elicit differences among goat genotypes in ME_m.
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1. Introduction

There are many different genotypes of goats in the world. Some have undergone natural selection for survival in particular environments, and others have been selected by man for high levels and (or) efficiencies of production, such as of meat, milk, and mohair fiber

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(Silanikove, 2000a,b). If and (or) how different development histories have impacted energy utilization is not well understood.

There are advantages and disadvantages of particular methods chosen to study energy utilization by goats as well as other ruminant species. One approach that can be and has been used is to measure change in BW and feed intake with regression analysis, which can be done in specific experiments or with compiled databases constructed from the literature. Large numbers of animals or treatment mean observations are required for this method, although normal production conditions can be used with relatively high feed intake. However, there are limitations, such as in some cases relying on assumptions of dietary ME concentration and assuming body composition to be similar among different genotypes, genders, and rate of BW change. Hence, such experiments may yield requirement estimates useful in a broad sense but that may not be most appropriate in specific settings. Another method is respiration calorimetry, which is expensive and requires appreciable technical expertise. With respiration calorimetry relatively small numbers of animals are used, conditions can be carefully controlled, different routes of energy loss are characterized, and efficiency of metabolism can be partitioned into various functions, such as maintenance, growth, and lactation. However, most calorimetry systems result in lower feed intake than in typical farm settings, to which minimal activity is a contributor. Therefore, it must be assumed that established relationships could be extrapolated to higher levels of feed intake and situations with greater energy expended in activity.

Methods of assessing energy utilization and requirements involving levels of intake above maintenance are necessary to study energy use for production but can complicate comparisons among genotypes of the maintenance requirement because of different efficiencies of energy use for accretion in tissue or fiber or secretion in milk. Furthermore, physical characteristics of diets may impact energy use by energetically expensive support tissues (Goetsch, 1998), thus suggesting a need to consider diet quality. Hence, the objective of this experiment was to characterize energy utilization by Alpine, Angora, Boer, and Spanish goats nearly 2 years of age fed a concentrate or forage based diet at a restricted level of intake near the maintenance requirement.

2. Materials and methods

2.1. Animals and diets

The treatment arrangement was a 4×2 factorial and the experimental design was four simultaneous crossovers.

Table 1
Composition of diets fed to Alpine, Angora, Boer, and Spanish wethers (% DM)

Item	Concentrate-based	Alfalfa hay
Ingredient		
Ground alfalfa hay	35.00	100
Ground corn	55.50	
Soybean meal	3.50	
Molasses	3.00	
Dicalcium phosphate	0.72	
Limestone	0.28	
Vitamin premix[a]	0.50	
Trace mineralized salt[b]	0.50	
Ammonium chloride	0.50	
Sodium sulfate	0.50	
Chemical composition		
Ash	6.1	8.0
CP	13.9	20.2
NDF	22.3	41.2
ADF	14.9	34.0
Acid detergent lignin	2.5	6.7

[a] Contained 2200 IU/g Vitamin A, 1200 IU/g Vitamin D_3, and 2.2 IU/g Vitamin E.
[b] Contained 95–98% NaCl and at least 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.011% Co, 0.007% I, and 0.005% Zn.

Twenty-four wethers, 19 months old at the start of the experiment, were used. There were six wethers of each of four genotypes: Alpine (47.7 ± 1.36 kg initial BW), Angora (28.8 ± 1.11 kg), Boer (87.5% Boer and 12.5% Spanish; 49.3 ± 2.17 kg BW), and Spanish (38.7 ± 0.51 kg BW). There were two–three sires represented for each genotype. Wethers were treated for internal parasites (Valbazen, SmithKline Beecham Animal Health, West Chester, PA) at the beginning of the experiment. There were two diets (Table 1): coarsely ground alfalfa hay (FOR) and concentrate based (CON). Diets were offered based on an assumed ME requirement for maintenance (ME_m) of 438 kJ/kg $BW^{0.75}$ (AFRC, 1998), initial BW, and ME concentrations of 9.2 and 11.3 MJ/kg DM for FOR and CON, respectively, determined from ingredient proportions and ME concentrations of NRC (1981). Diets were offered in two meals daily at 07:00 and 16:00 h. For wethers consuming FOR, 12 g/day of a mineral and vitamin supplement was top-dressed at the morning meal (26.1% dicalcium phosphate, 21.7% vitamin premix (Table 1), 21.7% trace mineralized salt (Table 1), and 30.5% dried molasses product).

Wethers resided in 1.05 m × 0.55 m elevated pens with plastic-coated expanded metal floors at most times. Water was available in small buckets free-choice except during times of gas exchange measurement, when given in buckets twice daily at 10:00 and 16:30 h for 3-min periods. Temperature (20–23 °C) and humidity (50–55%) were controlled on gas exchange measurement days. Because there were feed refusals in the first 15 days of the experiment, the level of offered feed was decreased by 10%. However, some feed refusals still occurred in the next 10 days, resulting in re-starting the experiment and a feeding rate of 80% of the initial one.

Table 2
Effects of diet quality on energy utilization by 20-months-old Alpine, Angora, Boer, and Spanish wethers

Item	Diet[a]	Genotype					Diet[a]		
		Alpine	Angora	Boer	Spanish	S.E.	CON	FOR	S.E.
BW (kg)									
Initial	Mean	47.7	28.8	49.3	38.7	1.44	42.1	40.1	2.25
Fed	CON	37.4	23.1	40.1	32.9	1.25			
	FOR	39.1	23.2	41.4	33.8				
	Mean	38.2c	23.1a	40.8c	33.3b	1.22	33.4	34.4	0.63
Fasted	CON	35.5	21.7	38.1	31.2	1.22			
	FOR	36.5	21.7	38.7	31.9				
	Mean	36.0c	21.7a	38.4c	31.5b	1.20	31.6	32.2	0.61
Digestion (%)									
DM	CON	69.2	79.8	80.0	78.9	1.73			
	FOR	63.2	62.4	63.7	59.8				
	Mean	71.2	71.1	71.8	69.3	1.30	79.5b	62.3a	0.86
OM	CON	81.8	82.1	82.7	81.8	1.68			
	FOR	65.7	64.8	65.9	62.3				
	Mean	73.7	73.4	74.3	72.1	1.29	82.1b	64.7a	0.84
CP	CON	81.3	80.5	79.8	78.2	0.83			
	FOR	79.0	78.2	80.8	79.1				
	Mean	80.2	79.4	80.3	78.7	0.61	79.9	79.3	0.41
NDF	CON	81.8	52.1	57.2	53.9	3.62			
	FOR	44.7	41.2	43.9	37.3				
	Mean	48.3	46.6	50.6	45.6	2.80	53.8b	41.8a	1.81
GE	CON	79.2	78.9	78.7	78.2	1.80			
	FOR	62.7	60.4	63.3	58.1				
	Mean	70.9	69.6	71.0	68.2	1.32	78.8b	61.1a	0.90
Intake									
DM (g/day)[b]	CON	557c	381a	574c	476c	14.1			
	FOR	673d	457b	700d	578c				
	Mean	615c	419a	637c	527b	13.8	497b	602b	7.0
N (g/day)	CON	12.4	8.5	12.8	10.6	0.41			
	FOR	21.8	14.7	22.6	18.7				
	Mean	17.1c	11.6a	17.7c	14.7b	0.39	11.1a	19.5b	0.21
GE (MJ/day)[b]	CON	9.92c	6.79a	10.21c	8.48b	0.258			
	FOR	12.37d	8.40b	12.88d	10.58c				
	Mean	11.14c	7.60a	11.55c	9.53b	0.251	8.85a	11.06b	0.129
DE (MJ/day)	CON	7.86	5.36	8.03	6.64	0.284			
	FOR	7.86	5.17	8.14	6.22				
	Mean	7.86c	5.27a	8.08c	6.43b	0.246	6.97	6.85	0.142
ME (MJ/day)	CON	6.70	4.65	6.77	5.67	0.282			
	FOR	6.56	4.40	6.71	5.17				
	Mean	6.63c	4.53a	6.74c	5.42b	0.239	5.94	5.71	0.141
ME (kJ/kg BW$^{0.75}$)	CON	461	465	443	430	16.2			
	FOR	439	438	431	385				
	Mean	450	451	439	408	12.6	450b	424a	8.1
Energy (MJ/day)									
Feces	CON	2.06	1.43	2.18	1.85	0.229			
	FOR	4.50	3.23	4.74	4.37				
	Mean	3.28b	2.33a	3.46b	3.11b	0.172	1.88a	4.21b	0.114
Urine	CON	0.63	0.38	0.69	0.47	0.054			
	FOR	0.95	0.53	0.95	0.72				
	Mean	0.79c	0.45a	0.82c	0.60b	0.030	0.544a	0.785b	0.027
Methane	CON	0.53	0.33	0.56	0.49	0.045			
	FOR	0.36	0.25	0.48	0.33				
	Mean	0.44bc	0.29a	0.52c	0.41b	0.032	0.48b	0.35a	0.023

Table 2 (*Continued*)

Item	Diet[a]	Genotype					Diet[a]		
		Alpine	Angora	Boer	Spanish	S.E.	CON	FOR	S.E.
N (g/day)									
Feces	CON	2.31	1.65	2.58	2.30	0.198			
	FOR	4.36	2.92	4.33	3.84				
	Mean	3.33b	2.28a	3.46b	3.07b	0.151	2.21a	3.86b	0.099
Urine	CON	7.41	5.72	9.85	8.27	0.910			
	FOR	13.99	7.93	12.58	9.96				
	Mean	10.70bc	6.82a	11.16c	9.12b	0.647	7.81a	11.09b	0.455
Energy expenditure (kJ/kg $BW^{0.75}$)									
Fed	CON	374	379	359	380	11.8			
	FOR	379	375	362	366				
	Mean	377	377	361	373	9.3	373	371	5.9
Fasted	CON	248	222	222	231	7.9			
	FOR	254	228	213	218				
	Mean	251b	224a	217a	225a	7.2	231	228	3.9
ME_m^c (kJ/kg $BW^{0.75}$)	CON	343	345	322	357	15.8			
	FOR	362	353	329	366				
	Mean	353	349	326	362	11.1	342	352	7.9
k_m^d	CON	0.729	0.663	0.691	0.657	0.0269			
	FOR	0.709	0.658	0.654	0.615				
	Mean	0.719b	0.660a	0.672a	0.636a	0.0148	0.685	0.657	0.0134

Letters a–d means in a mean row within genotype or diet grouping, or within genotype ×diet grouping, without a common letter differ ($P < 0.05$).
[a] CON, concentrate-based; FOR, alfalfa hay.
[b] Interaction between genotype and diet ($P < 0.05$), which was due to differences in magnitude.
[c] ME requirement for maintenance.
[d] Efficiency of ME use for maintenance.

2.2. Measurements and statistical analyses

Periods were 33 days long, consisting of 21 days of adaptation, 6 days for feces and urine collections, 2 days for gas exchange measures, and 4 days of fasting with gas exchange measures on the last 2 days. Wethers were divided into six sets of one genotype per set and two wethers on each of the two diets. Sets began the experiment at 2 days increments since the respiration calorimetry system consisted of four measurement units. Wethers were weighed at the beginning of the experiment, changes in level of feed intake, and the beginning and end of nutrient balance and gas exchange measurement times. Nutrient balance and gas exchange measurements were as described by Tovar-Luna et al. (in press). Prior to measures wethers had been placed in metabolism crates fitted with training head-boxes for adaptation. Before gas exchange measurements, validity and accuracy of expired CO_2 and inspired O_2 flows were checked with alcohol combustion (average 100.6 ± 0.8 and $99.7 \pm 1.1\%$ of expected CO_2 production and O_2 consumption, respectively).

Data were analyzed by mixed model analysis (Littell et al., 1996), with a repeated measure of period and random effect of animal within genotype. The only significant ($P < 0.05$) interactions between genotype and diet were in DM and GE intakes, which were however due to differences in magnitude rather than direction; thus, differences among both interaction and main effect means for these variables are addressed in Table 2.

3. Results

Wethers decreased in BW from the beginning of the experiment through the last nutrient balance segment (22.2, 20.1, 20.4, and 15.9% for Alpine, Angora, Boer, and Spanish, respectively; S.E. = 1.38). However, most of the change occurred from the beginning of the experiment to the first balance segment (78, 77, 71, and 56% for Alpine, Angora, Boer, and Spanish, respectively; S.E. = 7.7). Thereafter, BW did not markedly change.

Digestibilities were similar ($P > 0.05$) among genotypes (Table 2). Digestibilities of DM, OM, NDF, and GE were greater ($P < 0.05$) for CON than for FOR, and digestibility of CP was similar ($P > 0.05$) between diets. Differences ($P < 0.05$) among genotypes and between diets in intakes of DM, CP, GE, and DE were as expected. ME intake was slightly less ($P < 0.05$) for FOR than for CON as a result of a greater than assumed ME concentration in CON. As noted earlier, ME intake as well as EE and ME_m were expressed relative to fasted BW; values relative to fed BW were slightly lower.

Urinary energy and N losses were greater ($P < 0.05$) for FOR versus CON and varied among genotypes in accordance with differences in BW and level of intake (Table 2). Methane loss was greater ($P < 0.05$) for CON versus FOR in MJ/day and also as percentages of intakes of GE (5.4 and 3.2%) and DE (6.8 and 5.2% for CON and FOR, respectively).

EE when fed was similar ($P > 0.05$) between diets and among genotypes (Table 2). Fasted EE also was similar between diets but was greatest among genotypes ($P < 0.05$) for Alpine. As a result, the efficiency of ME utilization for maintenance (k_m) was greater ($P < 0.05$) for Alpine compared with other genotypes. ME_m was not influenced ($P > 0.05$) by genotype or diet.

4. Discussion

4.1. Genotype

ME_m, k_m, and fed and fasted EE were well aligned with findings of Tovar-Luna et al. (in press). In that experiment, reductions in feed intake similar to those before the present experiment had appreciable influence on EE and ME_m. This may explain why ME_m values of this experiment are in the low range of values summarized by AFRC (1998). Hence, these ME_m estimates cannot be directly extrapolated to conditions with higher levels of intake. For example, Tovar-Luna et al. (in press) noted ME_m 11% and 45 kJ/kg $BW^{0.75}$ less for crossbred Boer wethers of a similar age as ones of this experiment when fed at 80% of an initially assumed ME_m compared with 100% of ME_m.

In contrast to findings of the present experiment, based on regression of ME intake against BW change with a database of treatment mean observations compiled from the literature, Luo et al. (2004b) determined a greater ME_m for growing Alpines than for meat and indigenous or local genotypes. Furthermore, Urge et al. (2004) reported a lower efficiency of feed utilization for growth by Alpine versus Boer and Angora wethers; efficiency of feed utilization by Spanish wethers was similar to that for Alpine, but low efficiency for Spanish appeared due to relatively low feed intake per unit $BW^{0.75}$. Similarly, Silanikove (1986) through a direct comparison reported that Bedouin goats on a very limited nutritional plane had a ME_m approximately 50% of that of Saanen goats. Although it seems reasonable that goats that have developed in environments, such as deserts would have low basal metabolic rates and ME_m (Silanikove, 2000a,b), results of recent studies (Asmare et al., 2006; Ngwa et al., 2006) imply that other nondairy goat genotypes may also have capacity to markedly

reduce EE with very limited ME intake. However, it is important to note that in the present experiment the level of ME intake was near the assumed ME_m and not very low, such as 40–60% of the assumed ME_m as used by Silanikove (1986), Asmare et al. (2006), and Ngwa et al. (2006).

Greater fasted EE for Alpines than for other genotypes was not expected given similar fed EE. Although there was not a direct assessment of behavior, based on casual observations Alpine wethers were more active when fasted than were wethers of other genotypes. Factors responsible for this behavior difference are unclear, as all wethers were well accustomed to the experimental procedures and, in fact, were used when younger in the experiment of Urge et al. (2004). A portion of the genotype difference in fasted EE may have resulted from disparate activity during measurement; however, the substantial difference (13% greater fasted EE for Alpine compared with the mean for other genotypes) suggests involvement of other factors.

The genotype difference in fasted EE does not appear attributable to proportions of fat and protein in tissue being catabolized given the respiratory quotient (0.78, 0.77, 0.79, and 0.77 for Alpine, Angora, Boer, and Spanish, respectively; S.E. = 0.006). Therefore, a difference between the Alpine and other goats in total body composition or metabolic activity per unit of tissue was presumably responsible for the difference in fasted EE. Perhaps splanchnic tissue mass and energy use is greater for goat breeds selected for milk production than for other genotypes, as is thought to cause greater ME_m for dairy versus beef cattle breeds (NRC, 2000).

Alpines displayed an ability to limit EE when ME intake was near the assumed ME_m to an extent similar to that for other goat genotypes but not when the ME intake restriction was fasting. This finding is somewhat in accordance with differences observed by Silanikove (1986) in BW and body solids between Saanen and Bedouin goats when consuming forage diets varying in nutritive value (i.e., alfalfa hay, Rhodes grass mixed with alfalfa hay, and wheat straw). Furthermore, perhaps an alternative diet in the present experiment, such as one based on forage rather than that largely of concentrate, would have resulted in a different ability of Alpines to reduce fed EE compared with other goat genotypes.

ME_m for Angora similar to other goat genotypes contrasts findings of another recent experiment. By regression of ME intake against tissue and clean mohair fiber gain with a compiled database of treatment mean observations from the literature, Luo et al. (2004a) estimated a ME_m for Angora goats greater than Luo et al. (2004b) determined for mature dairy and indigenous and growing

meat and indigenous goats. Again, a lower level of feed intake in the present experiment compared with those for observations used by Luo et al. (2004a) may have contributed to this disparity.

This experiment did not include a level of intake markedly above ME_m since animals were not lactating or growing. Thus, based on findings of Luo et al. (2004a,b), it is possible that with such animals and their higher nutrient requirements, levels of ME intake above maintenance would have resulted in relationships between EE and ME intake that differed among genotypes. Further research is required to address this possibility.

4.2. Diet

k_m was lower than predicted based on the AFRC (1998) equation $k_m = 0.503 + (0.019 \times ME, MJ/kg\ DM)$ (i.e., 0.730 and 0.683 for CON and FOR, respectively). This disparity could have resulted in part from energy accretion during the gas exchange measurement period because of less efficient energy utilization for accretion than for physiological processes associated with maintenance at a restricted level of intake. However, change in efficiency of energy use as feed intake increases from fasting is gradual rather than abrupt. Also, k_m and the efficiency of ME use for gain as often determined with respiration calorimetry, involving measurement of EE when fasting and at levels of intake near maintenance, may differ largely because of the relatively high efficiency with which mobilized body tissue energy is used for support of essential body functions along with minimal heat production by visceral tissues while fasting. ME_m corrected for retained energy was not presented because efficiency of energy metabolism varies among individuals and the need for assumptions of the efficiency of ME use for gain and energy concentration in accreted tissue. Moreover, efficiency of metabolism varies among specific tissues being accreted, such as mohair fiber, fat, and protein. Employment of such assumptions would introduce potential for additional bias. Nonetheless, even though retained energy was similar among three of the four genotypes, these ME_m and k_m values should have greatest value for treatment comparisons within this experiment.

Numerically, greater k_m for CON than for FOR, though not significantly different, is in accordance with reviews of AFRC (1998) and NRC (2000, 2001). However, with other ruminant species higher levels of feed intake have resulted in a greater influence of dietary concentrate level on k_m (ARC, 1980; NRC, 2000, 2001). This may be explained by how energy use by various tissues is classically partitioned into that for maintenance

and gain (Williams and Jenkins, 2003). It would appear that energy utilization for support of tissue or fiber accretion or lactation is influenced by the nature of the diet (e.g., concentrate and fiber levels) more than energy use for maintenance at restricted levels of intake near maintenance.

Methane emission is typically greater for forage than for concentrate based diets when fed to provide similar ME (Johnson and Johnson, 1995), which was not observed in the present experiment. This may have resulted from use of alfalfa as the FOR diet, since leguminous forage diets result is less methane production than grass based diets (Benchaar et al., 2001).

5. Summary and conclusions

Genotypes of this experiment differ in development history. Alpine goats have been selected for milk production, Boer for growth rate, size, and meat production, and Angora for mohair fiber growth. Spanish goats have been subjected to less selection for production attributes than the other genotypes used. Breeding for specific characteristics and unique development pasts can impact how animals respond to environmental conditions. Based on fasting measures of this experiment, it would appear that dairy goat breeds like Alpine cannot minimize EE to the extent of other genotypes in response to very severe nutrient restriction, such as fasting, even if preceded by a level of ME intake near a ME_m assumed for a constant and nonlimiting nutritional plane rather than one much greater. However, these results do not preclude the possibility of differences among genotypes in ME_m with production classes of goats that have relatively high nutrient requirements and are fed at higher levels of intake.

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